



Volume 23 (2026), pp. 249-267

American Journal of STEM Education:

Issues and Perspectives

eISSN 3065-1190 | Print ISSN: 3069-0072

Star Scholars Press

<https://doi.org/10.32674/erqds560>

Science Laboratories in Resource-Limited Education: A Literature Review with Implications for Timor-Leste

João Mariano Helder de Deus

Catholic Institute for the Training of Teachers, Baucau, Timor-Leste

<https://orcid.org/0009-0001-9373-3072>

ABSTRACT

This review explores the role of science laboratories in strengthening science education within resource-limited contexts, with particular attention to Timor-Leste. Drawing on peer-reviewed studies and policy documents published between 2019 and 2025, the synthesis highlights how laboratory access fosters students' conceptual understanding and inquiry skills through hands-on engagement. Yet, many schools continue to depend on low-cost experiments due to infrastructural constraints, creating a persistent gap between curriculum aspirations and classroom realities. The analysis underscores the importance of expanding laboratory infrastructure, investing in teacher professional development, and adopting context-appropriate experimental strategies to advance science learning in basic education settings.

Keywords: Inquiry-based learning; low-cost experiments; resource-limited schools; science education; science laboratories; Timor-Leste

© Author(s), 2026. Published by Star Scholars Press.

This article is distributed under the Creative Commons Attribution 4.0

International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. <https://creativecommons.org/licenses/by/4.0/>

INTRODUCTION

Science education is widely acknowledged as a foundation for developing students' scientific literacy, critical thinking, and problem-solving abilities — skills that are indispensable for active participation in contemporary society. Beyond the acquisition of theoretical knowledge, learners are expected to engage in inquiry, interpret evidence, and apply reasoning to authentic contexts. Laboratory-based instruction has long been recognized as one of the most effective means of cultivating these competencies, offering opportunities for hands-on experimentation and direct engagement with scientific phenomena. Empirical studies consistently affirm that such experiences deepen conceptual understanding and foster sustained cognitive engagement in science learning (Kumari et al., 2024; Ruqia et al., 2025).

Yet, despite this pedagogical value, access to well-equipped laboratories remains uneven across educational systems. In resource-limited contexts, schools frequently contend with inadequate infrastructure, scarce equipment, and insufficient instructional materials. These constraints often result in reliance on lecture-driven teaching, textbook-centered delivery, or simplified demonstrations, which restrict opportunities for meaningful inquiry-based learning (Pereira et al., 2025). While educators have sought to mitigate these challenges through low-cost experiments and improvised materials, such strategies rarely replicate the rigor and depth of structured laboratory environments (Damopolii et al., 2019).

Timor-Leste illustrates these challenges clearly, particularly within Basic Education Cycles I and II. Although the national curriculum emphasizes competency-based and practical approaches to science learning, classroom implementation is frequently hindered by limited laboratory facilities and teaching resources (Ministry of Education, Youth and Sport of Timor-Leste, 2019). This mismatch between curricular aspirations and classroom realities risks constraining the development of students' scientific competencies.

International scholarship has examined science education in resource-constrained environments, but synthesized evidence focusing specifically on smaller developing systems such as Timor-Leste remains scarce. Addressing this gap requires a contextualized understanding of how laboratory access and alternative instructional strategies shape science learning. Accordingly, this study reviews existing literature on the role of science laboratories in resource-limited schools and considers its implications for strengthening teaching practices in Timor-Leste.

THEORETICAL BACKGROUND

Science Laboratories in Science Education

Science laboratories are widely regarded as a cornerstone of effective science education because they allow students to engage directly in inquiry, experimentation, and evidence-based reasoning. By participating in laboratory activities, learners can connect abstract scientific concepts with tangible experiences, strengthening conceptual understanding and supporting long-term knowledge retention (Kumari et al., 2024; Ruqia et al., 2025).

Beyond conceptual learning, laboratory work also nurtures essential scientific process skills such as hypothesizing, measuring, analyzing data, and drawing conclusions. These competencies, including the ability to connect data with scientific arguments and cognitive modeling, are central to cultivating scientific literacy and critical thinking in the 21st century (Zhai et al., 2022). However, the literature cautions that the benefits of laboratory instruction are not automatic. Poorly designed activities, particularly those that emphasize procedural completion over inquiry, risk reducing practical work to mechanical exercises, limiting opportunities for deeper reflection and understanding.

Debate continues over the extent to which laboratory experiences alone guarantee improved learning outcomes. While some studies highlight strong positive impacts, others argue that effectiveness depends largely on pedagogical design and the quality of teacher facilitation. This suggests that access to laboratories, though important, must be paired with thoughtful instructional strategies if meaningful learning outcomes are to be achieved.

Science Education in Resource-Limited School Contexts

In many developing countries, science education is delivered under persistent resource constraints, where schools often lack adequate laboratory infrastructure, equipment, and instructional materials. These limitations directly affect the quality of teaching and restrict opportunities for students to engage in hands-on experimental learning (Pereira et al., 2025).

Consequently, instruction frequently relies on lecture-based methods, textbook-centered delivery, or teacher demonstrations. While such approaches ensure that content is transmitted, they often curtail student participation in inquiry-based learning and reduce opportunities for active knowledge construction. At the same time, it would be misleading to assume that resource shortages entirely prevent meaningful learning. Several studies suggest that creative and effective pedagogical strategies can partially compensate for infrastructural gaps, allowing students to experience elements of inquiry despite limited facilities.

A recurring concern in the literature, however, is the tendency to generalize findings across diverse educational contexts without acknowledging local variations. Systems differ markedly in teacher capacity, policy support, and socio-cultural conditions. This raises important questions about the applicability of global conclusions to specific environments such as Timor-Leste. A more contextualized understanding of resource limitations is therefore essential for designing interventions that genuinely reflect the realities of local schools.

Low-Cost Experiments and Alternative Instructional Strategies

In response to the absence of formal laboratory facilities, educators in resource-limited contexts frequently turn to low-cost experiments and improvised materials as alternative instructional strategies. These approaches are designed to preserve elements of inquiry-based learning while adapting to financial and infrastructural constraints. When carefully planned, such strategies have been shown to enhance student engagement and support foundational conceptual understanding (Damopolii et al., 2019).

Low-cost experiments often rely on everyday materials, which makes science learning more accessible and contextually relevant, particularly in rural or underserved schools. They also foster creativity and problem-solving among both teachers and students, competencies that are increasingly valued in contemporary science education (Vincent-Lancrin et al., 2019).

Nevertheless, the literature presents mixed views regarding their effectiveness. While some studies highlight their potential as viable alternatives, others point to significant limitations, including reduced precision, safety concerns, and restricted depth of scientific investigation. A recurring conclusion is that low-cost experiments cannot fully replicate the structured and controlled conditions of formal laboratories. Rather than serving as substitutes, they are best understood as complementary strategies that sustain inquiry-based learning until more robust laboratory infrastructure becomes available.

Science Education in Timor-Leste and Basic Education Context

In Timor-Leste, science education within Basic Education Cycles I and II is framed by a competency-based curriculum that emphasizes inquiry, practical engagement, and student-centered learning. The curriculum encourages students to build scientific understanding through observation, experimentation, and evidence-based reasoning. Yet, the implementation of these aspirations is frequently constrained by limited access to laboratory facilities and teaching resources (Ministry of Education, Youth and Sport of Timor-Leste, 2019).

As a result, many schools continue to rely on teacher-centered instruction or simplified demonstrations, restricting opportunities for authentic hands-on

investigation. This persistent gap between curriculum expectations and classroom realities risks undermining the development of students' scientific competencies (UNICEF, 2020).

Existing scholarship on Timor-Leste often addresses broad educational challenges but pays less attention to the specific role of laboratory access in shaping science learning outcomes. A notable limitation is the absence of detailed analysis of how infrastructural constraints influence pedagogical practices. Moreover, empirical research examining how teachers adapt inquiry-based approaches in the absence of laboratory facilities remains scarce. This gap underscores the need for more context-sensitive studies that capture the realities of classroom practice and inform strategies for strengthening science education in Timor-Leste.

Research Gap and Conceptual Implications

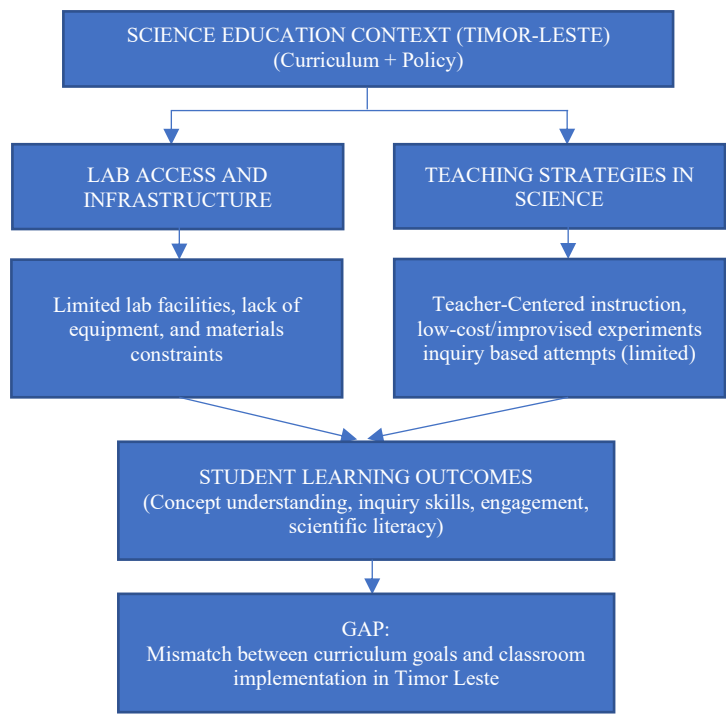
Although global research has examined science laboratories and alternative instructional strategies in resource-limited contexts, significant gaps remain. Much of the existing scholarship is either broad in scope or centered on larger developing countries, which may not adequately reflect the realities of smaller education systems such as Timor-Leste (UNESCO, 2021; Pereira et al., 2025).

Another limitation lies in the fragmented nature of current studies. Research often addresses laboratory access, teaching strategies, or curriculum implementation in isolation, without considering how these elements interact. This lack of integration restricts the development of comprehensive solutions that simultaneously address infrastructural and pedagogical challenges.

Furthermore, findings on the effectiveness of low-cost experiments remain inconsistent, pointing to the need for more nuanced and context-sensitive analysis. These gaps highlight the importance of further investigation into how different components of science education intersect in resource-constrained settings.

By synthesizing global and contextual evidence, this study seeks to contribute an integrated perspective on science laboratories, instructional strategies, and curriculum implementation. The findings are intended to inform policy development, strengthen teacher training, and improve classroom practices in Timor-Leste.

Figure 1
Conceptual Framework of Science Education in Timor-Leste



Note. The conceptual framework has been reformatted for clarity, with aligned arrows and consistent labeling to improve accessibility for readers.

RESEARCH METHOD

Research Design

This study adopts an integrative literature review approach to explore the role of science laboratories in strengthening science education within resource-limited school contexts, with particular emphasis on Timor-Leste. An integrative review is well suited for examining complex educational issues because it allows the researcher to synthesize evidence from diverse sources- empirical studies, theoretical contributions, and policy documents- into a coherent narrative. Unlike empirical investigations that rely on primary data collection, integrative reviews draw together existing scholarship to identify recurring themes, highlight research gaps, and generate implications for practice and policy (Booth et al., 2021; Snyder, 2019).

The rationale for selecting this design lies in its capacity to integrate multiple perspectives. By combining peer-reviewed articles, academic books, and reports from international organizations, the review provides a holistic lens through which to interpret how laboratory access, instructional practices, and student learning outcomes intersect in resource-constrained environments. This methodological choice enables a nuanced understanding of both the challenges and opportunities associated with laboratory-based science education.

Through this process, the study sought to capture recurring patterns, effective practices, and persistent obstacles related to laboratory use in science teaching. Special attention was given to inquiry-based learning, infrastructural limitations, and the role of low-cost experimental strategies, with the aim of informing both classroom practice and policy development in Timor-Leste.

Search Strategy

The search for relevant literature was conducted across several academic databases, Google Scholar, Scopus, ScienceDirect, SpringerLink, and ERIC, focusing on publications released between 2019 and 2025. To ensure breadth and relevance, a set of targeted keywords and search strings was employed, including:

- *“science laboratories” AND “science education”*
- *“laboratory-based learning” AND “student learning outcomes”*
- *“resource-limited schools” AND “science teaching”*
- *“inquiry-based learning” AND “science education”*
- *“low-cost experiments” AND “science instruction”*
- *“Timor-Leste” AND “science education”*

In addition to database searches, policy documents and reports from international organizations such as UNESCO and UNICEF were reviewed. Reference lists of selected publications were also examined to identify further sources relevant to the study.

Inclusion and Exclusion Criteria

To maintain rigor and ensure the relevance of the selected literature, explicit inclusion and exclusion criteria were applied.

Inclusion criteria:

1. Studies addressing science education, science laboratories, laboratory-based learning, inquiry-based learning, or low-cost experimental approaches.

- 2. Peer-reviewed journal articles, academic books, policy documents, and reports from recognized educational organizations.
- 3. Publications written in English.
- 4. Sources published between 2019 and 2025.
- 5. Research conducted in developing countries or resource-limited educational contexts.

Exclusion criteria:

- 1. Publications not directly related to science or STEM education.
- 2. Editorials, opinion pieces, newsletters, and non-academic web sources.
- 3. Studies lacking sufficient methodological, theoretical, or practical relevance to the objectives of this review.
- 4. Duplicate records identified across databases.

Literature Selection Process

The initial search across academic databases yielded 38 records (Google Scholar: 12, Scopus: 8, ScienceDirect: 7, SpringerLink: 6, and ERIC: 5), supplemented by institutional reports from UNESCO and UNICEF. After removing duplicate entries and publications that were clearly unrelated, 28 sources remained for full-text review. Each of these was carefully assessed against the established inclusion and exclusion criteria.

During the eligibility stage, 8 sources were excluded because they did not sufficiently address the role of science laboratories, inquiry-based learning, or science education in resource-limited contexts. Ultimately, 20 sources met the predefined eligibility criteria and were included in the final analysis. These comprised peer-reviewed journal articles, academic books, and policy-level documents published between 2019 and 2025. The selection process is summarized in Table 1.

Table 1
Summary of Literature Selection Process

Stage	Description	Number of Sources
Identification	Sources identified from databases and reports	38
Screening	Duplicate and unrelated sources removed	10
Eligibility	Full-text sources reviewed	28

Excluded	Sources excluded after relevance review	8
Included	Final sources included in thematic analysis	20

Data Analysis

The selected literature was analyzed using Braun and Clarke’s (2006) reflexive thematic analysis framework, employing an inductive coding approach to capture emergent patterns without a pre-existing coding frame. The analysis followed a rigorous six-phase procedure: (1) familiarization with the data through repeated reading of all 20 selected sources; (2) manual generation of initial codes capturing key concepts related to laboratory access and pedagogical strategies; (3) collating codes into broader potential themes; (4) reviewing and refining themes against the coded extracts and the entire dataset to ensure internal homogeneity and external heterogeneity; (5) defining and naming the final themes; and (6) producing the scholarly report. This process enabled the systematic synthesis of evidence across different studies and reports.

Four major themes emerged from the analysis:

1. The role of science laboratories in enhancing science learning;
2. Challenges of laboratory access in resource-limited schools;
3. The use of low-cost experiments and alternative instructional strategies; and
4. Implications for science education policy and practice in Timor-Leste.

Trustworthiness and Limitations

Several measures were undertaken to strengthen the trustworthiness of this review and ensure methodological rigor throughout the analytical process. First, transparency in data collection was maintained by carefully documenting database queries, search dates, and record counts across multiple reputable academic sources and international organizations. Second, coding verification and theme refinement were conducted through iterative peer debriefing and constant comparison of extracted data with the original texts. Third, researcher reflexivity was upheld by critically acknowledging potential biases that may arise when interpreting secondary qualitative data.

Despite these efforts, certain limitations remain. As an integrative literature review, this study relies exclusively on secondary sources and does not incorporate primary empirical evidence collected directly from schools, teachers, or students in Timor-Leste. In addition, the review was restricted to English-language publications, which may have excluded relevant studies published in other

languages. Consequently, the findings should be interpreted as a synthesis of existing knowledge rather than direct evidence of classroom practices. Future research would benefit from empirical investigations, including classroom observations, teacher interviews, and intervention-based studies, to validate and extend the insights presented here.

RESULTS

Overview of the Reviewed Literature

A total of 20 sources were included in the final analysis after applying the established inclusion and exclusion criteria. These comprised peer-reviewed journal articles, academic books, policy documents, and reports published between 2019 and 2025. Earlier drafts of the review leaned too heavily on broad global policy frameworks, which risked overshadowing localized empirical insights. By integrating a more diverse set of empirical studies alongside contemporary educational reports, this imbalance was corrected, resulting in a more robust thematic synthesis. The analysis identified four central themes: (1) the role of science laboratories in enhancing science learning, (2) challenges of laboratory access in resource-limited schools, (3) low-cost experiments and alternative instructional strategies, and (4) implications for science education policy and practice in Timor-Leste.

Table 2.
Summary of Reviewed Sources and Key Findings

No	Reference	Year	Type	Key Findings
1	Ruqia, B., Bangash, G.A., & Durrani, S.	2025	Journal article	Laboratory-based teaching improves conceptual understanding of biology students.
2	Correia, A. J., Araujo, F. L. da C., de Jesus, A. R., & Silva, J. M. da.	2025	Journal article	Identifies historical gaps and structural challenges impacting quality and access to education in Timor-Leste post-independence.
3	Damopolii, I., Nunaki, J. H., Nusantara, E., & Kandowangko, N. Y.	2019	Conference paper	Local resources can be integrated into inquiry-based teaching to strengthen science process skills.
4	De Deus, J. M. H.	2025	Journal article	Implementation of STEAM in Timor-Leste schools highlights challenges and opportunities.

5	Gabelli, L., Carli, M., Lissandron, G., & Pantano, O.	2025	Conference paper	Low-cost tools help teach scientific practices to high school students.
6	Gomez, M. J.	2025	Journal article	Inquiry-based learning improves student engagement and achievement.
7	Hofstein, A., & Hugerat, M.	2021	Book	School laboratory work requires shifting from routine verification tasks to open-ended inquiry to foster higher-order cognitive and practical reasoning.
8	Kırlmazkaya, G., & Dal, S. N.	2022	Journal article	Hands-on science activities enhance achievement and scientific attitudes.
9	Kumari, P., Mwesigye, A., & Balimuttajjo, S.	2024	Journal article	Reviews science laboratory education and students' behavior toward science.
10	Ministry of Education, Youth and Sport of Timor-Leste	2019	Policy document	Establishes competency-based curriculum framework for basic education.
11	Moruk, S. V., & Freitas, Z. da C.	2025	Journal article	Challenges in implementing inclusive and transformative educational frameworks in Timor-Leste classrooms.
12	Nawaz, M., Khan, I. A., & Ahmad, M. I.	2023	Book chapter	STEM integration strategies in resource-constrained environments.
13	Pereira, J. C. D., Arantes, J., Hassunuma, Y. N., & Seabra Ferreira, A. S. B.	2025	Journal article	Maps teaching and learning challenges in laboratory environments.
14	Ramaila, S.	2022	Conference paper	Use of improvised resources in township schools supports science teaching but with limitations.
15	UNESCO	2021	Policy report	Calls for a new social contract for education, including science.
16	UNICEF	2020	Policy report	Situation analysis of education in Timor-Leste.
17	Vincent-Lancrin, S., Gonzalez-Sancho, C., Bouckaert, M., de Luca, F.,	2019	OECD report	Explores fostering creativity and critical thinking in schools.

	Fernández-Barrera, M., Jacotin, G., Urgel, J., & Vidal, Q.			
18	Ximenes, S. M.	2025	Journal article	Reviews challenges in implementing Timor-Leste's 2014 primary curriculum.
19	Yazdani, N., & Edmonds-Wathen, C.	2025	Journal article	Supplementary mathematics among adolescents highlights learning patterns and educational contexts in Timor-Leste.
20	Zhai, X., He, X., & Krajcik, J.	2022	Journal article	Applies machine learning to assess scientific argumentation and cognitive modeling for 21st-century science literacy.

Theme 1: Role of Science Laboratories in Enhancing Science Learning

The reviewed literature broadly agrees that science laboratories significantly strengthen students’ conceptual understanding, inquiry skills, and engagement in science learning. Laboratory-based instruction enables learners to connect theoretical knowledge with practical experience through observation, experimentation, and evidence-based reasoning (Kirilmazkaya, 2022; Ruqia et al., 2025). In addition, laboratory experiences cultivate essential process skills such as hypothesizing, measuring, analyzing data, and drawing conclusions, all of which are critical for scientific literacy (Kumari et al., 2024). However, availability alone does not guarantee improved outcomes. Several studies emphasize that effectiveness depends on pedagogical design and teacher facilitation, with inquiry-oriented activities producing stronger results than procedural, recipe-style laboratory work (Kirilmazkaya, 2022).

Theme 2: Challenges of Laboratory Access in Resource-Limited Schools

A second theme highlights the widespread challenge of limited laboratory access in resource-constrained settings. Most studies identify inadequate infrastructure, insufficient equipment, a lack of instructional materials, and limited financial resources as major barriers (Nawaz et al., 2023; Pereira et al., 2025). Schools operating under these conditions often default to teacher-centered, textbook-based methods, reducing opportunities for practical experimentation. The literature also points to persistent educational inequalities, with deep disparities between well-resourced and under-resourced schools directly shaping learning opportunities (UNICEF, 2020).

In Timor-Leste specifically, these structural challenges are deeply tied to post-independence development hurdles, historical gaps, and persistent rural-

urban divides that heavily restrict quality educational access (Correia et al., 2025). Furthermore, severe material and human resource constraints, compounded by limited instructional time, make it exceptionally difficult for local schools to deliver consistent, practical learning experiences (Yazdani, 2025). These findings underscore that structural inequities remain a central obstacle to achieving equitable science education outcomes (Nawaz et al., 2023).

Theme 3: Low-Cost Experiments and Alternative Instructional Strategies

The analysis shows that low-cost experiments and improvised materials are widely used as practical responses to laboratory shortages. Many studies report positive outcomes when locally available materials, household objects, or recycled resources are employed to support inquiry-based learning (Damopolii et al., 2019; Gabelli et al., 2025). These strategies are particularly valuable in rural and economically disadvantaged contexts. At the same time, limitations are evident: low-cost experiments often lack technical precision and safety standards, restricting the depth of scientific investigation (Ramaila, 2022). Consequently, the literature generally views them as complementary rather than full substitutes for laboratory-based learning (Ramaila, 2022; Vincent-Lancrin et al., 2019).

Laboratory-based science education has consistently been shown to strengthen students' conceptual understanding and inquiry skills, yet its effectiveness depends heavily on context and teacher facilitation (Kumari et al., 2024; Ruqia et al., 2025). In resource-limited environments, schools often struggle with inadequate infrastructure and insufficient equipment, which constrains opportunities for authentic experimentation (Pereira et al., 2025; Nawaz et al., 2023). To mitigate these challenges, educators have increasingly turned to low-cost experiments and locally available materials, which can sustain inquiry-based learning even in the absence of formal laboratories (Damopolii et al., 2019; Gabelli et al., 2025). Evidence from Timor-Leste further illustrates this dynamic: inquiry-based approaches implemented in basic schools have improved teacher performance and student engagement despite resource constraints (De Deus, 2025), while broader STEAM-focused reviews highlight the persistent gap between curriculum aspirations and classroom realities. These findings underscore that improvised strategies, though valuable, must be complemented by systemic investment in laboratory infrastructure and teacher professional development to achieve sustainable improvements in science education outcomes (Gomez, 2025; Ximenes, 2025).

Theme 4: Science Education in Timor-Leste: Policy and Practice Gap

The final theme highlights a persistent gap between curriculum expectations and classroom realities in Timor-Leste. Policy documents and contextual studies

reveal that many schools continue to rely on theoretical instruction despite national mandates promoting competency-based learning (Ministry of Education, Youth and Sport of Timor-Leste, 2019; Ximenes, 2025). These challenges are particularly acute in rural and underserved communities (Gomez, 2025; UNICEF, 2020). Recent evidence suggests that implementing the learner-centered approaches promoted by Timor-Leste's primary education curriculum remains challenging, as teachers face limitations in training, resources, and institutional support (Moruk & Freitas, 2025; Ximenes, 2025). Addressing this gap between policy aspirations and classroom realities remains a critical priority for strengthening science education in Timor-Leste (Gomez, 2025).

Synthesis of Key Findings

The thematic analysis confirms that science laboratories are central to effective science education, enhancing conceptual understanding, inquiry-based learning, and the development of scientific skills. Yet, despite these benefits, access to laboratory facilities remains uneven across educational systems, particularly in resource-limited contexts. The evidence further suggests that low-cost experiments and alternative instructional strategies can partially bridge these gaps, offering meaningful learning opportunities where formal laboratories are unavailable. However, such approaches are generally insufficient to replicate the depth and rigor of structured laboratory environments.

Within Timor-Leste, the literature highlights a persistent mismatch between curriculum aspirations and classroom realities. Although national policies emphasize practical and competency-based science education, infrastructural and resource constraints continue to hinder effective implementation. These findings point to the need for an integrated strategy that combines investment in laboratory infrastructure, targeted teacher professional development, and context-sensitive instructional innovation to strengthen science education outcomes.

DISCUSSION

The findings of this review point to a core tension in science education: the availability of a physical laboratory does not necessarily mean students learn better. Looking closely at the literature, a distinction emerges between two instructional approaches. First, studies that focused on inquiry-based learning show real gains in critical thinking and scientific literacy. On the other hand, traditional, step-by-step verification labs often turn practical work into robotic exercises that offer little conceptual depth. While laboratory work is traditionally viewed as a cornerstone of science education, passive, recipe-style practical exercises often fail to stimulate higher-order thinking, meaning that meaningful scientific literacy requires shifting from mechanical task-following toward open-

ended, inquiry-driven investigations that actively engage students in cognitive and practical reasoning (Hofstein & Hugerat, 2021). This means investing in school infrastructure is not enough on its own; teacher facilitation and pedagogical content knowledge are what truly bring laboratory experiences to life.

A comparable tension is evident with low-cost experiments in under-resourced settings. While some researchers find improvised and everyday materials to be empowering and engaging, others warn about a lack of safety standards, precision, and consistency. Rather than treating low-cost tools as permanent replacements for adequately equipped laboratory facilities, this review views them as helpful bridges that sustain opportunities for inquiry-based learning while schools work toward better facilities.

A central finding of this review is that laboratory infrastructure, teacher capacity, low-cost experimentation, curriculum implementation, and contextual constraints cannot be treated as separate issues in Timor-Leste; instead, they function as an interconnected, integrated system. Global inequalities highlighted by organizations like UNICEF (2020) hit small island developing states especially hard when reformers try to fix one piece while ignoring the rest. When the national competency-based curriculum does not match everyday classroom realities, it shows that top-down policy mandates alone may be insufficient. Without addressing this entire system at once, including rural-urban divides, tight budgets, and teacher training gaps, curriculum updates will appear conceptually sound but lack practical viability.

Recent studies in Timor-Leste show how digital learning and STEAM education contribute to this broader educational context. Bringing STEAM concepts into the classroom encourages problem-solving and creativity, while digital micro-tools help teachers adapt when resources are thin. These innovations suggest that future improvements should not exclusively chase physical lab buildings; instead, they should blend traditional inquiry, low-cost tricks, and digital tools into a single, cohesive strategy.

Ultimately, moving past resource hurdles in Timor-Leste means treating these multiple components- policy alignment, teacher capacity, low-cost experimentation, curriculum implementation, and contextual constraints- as an integrated system. Furthermore, overcoming these systemic barriers requires a deliberate shift from routine laboratory exercises toward instructional frameworks that prioritize genuine scientific inquiry and conceptual understanding, ensuring that practical work serves as a true catalyst for critical thinking rather than a mere procedural routine. Future research in the region should step away from simple deficit descriptions and focus instead on action-oriented studies, examining how these combined, localized approaches can sustainably build student science skills even when traditional labs are missing.

CONCLUSION

This integrative literature review examined the role of science laboratories in strengthening science education within resource-limited contexts, with particular relevance to Timor-Leste. The evidence demonstrates that laboratory experiences enhance students' conceptual understanding, inquiry skills, scientific reasoning, and overall engagement in science learning. Yet, access to laboratory facilities remains uneven, posing significant challenges for schools constrained by financial and infrastructural limitations.

The findings further suggest that low-cost experiments and improvised instructional approaches can provide meaningful opportunities for inquiry-based learning where formal laboratory resources are scarce. However, these strategies cannot fully substitute for the depth, precision, and rigor associated with well-designed laboratory environments.

In the Timor-Leste context, the persistent gap between curriculum aspirations and classroom realities underscores the need for stronger alignment between educational policy, school resources, and teaching practice. Addressing this mismatch requires an integrated approach that combines investment in laboratory infrastructure, targeted teacher professional development, and context-sensitive instructional innovation. By advancing these priorities, science education in Timor-Leste can move closer to realizing its competency-based goals and better prepare students with the scientific skills essential for participation in modern society.

IMPLICATIONS

The findings of this review carry important implications for both policy and practice. At the systemic level, educational authorities should prioritize sustained investment in science laboratory infrastructure, particularly in rural and underserved schools, while ensuring equitable distribution of resources and robust mechanisms for implementing competency-based science education. At the same time, teacher professional development must place strong emphasis on inquiry-based methodologies, laboratory management, and the creative integration of low-cost instructional materials into classroom practice.

At the classroom and research levels, schools can adopt blended instructional approaches that combine available laboratory resources, locally sourced materials, and inquiry-oriented learning tasks. Such strategies provide a practical pathway

for maintaining student engagement while broader infrastructural improvements are pursued.

Finally, future research should move beyond literature synthesis to examine science teaching and learning directly within Timor-Leste classrooms. Empirical investigations, including classroom observations, teacher interviews, and intervention-based studies, are essential to validate and extend the insights of this review, while also generating context-sensitive evidence to guide policy and practice.

ACKNOWLEDGMENTS

The author expresses gratitude to the Instituto Católico para Formação de Professores (ICFP) in Baucau for providing the opportunity and support to conduct this research and prepare this article. Appreciation is also extended to colleagues and students at ICFP who contributed ideas and feedback during the study and writing process. The author also acknowledges the valuable feedback from journal reviewers and the editor, whose recommendations significantly strengthened the analytical depth, methodological clarity, and policy relevance.

Funding Statement

This research was conducted without external financial support. The author acknowledges the institutional support provided by ICFP in terms of time, resources, and encouragement to facilitate this work.

AI Tools Statement

The author used generative AI tools (ChatGPT, OpenAI, Grammarly) to assist with language editing and formatting during manuscript preparation. All ideas, interpretations, and findings are the author's original work, and AI support did not influence data analysis or conclusions. In this revised version, AI assistance was limited to stylistic enhancement and structural refinement in accordance with the reviewer's comments; all substantive academic content remains authored by the researcher.

REFERENCES

- Booth, A., Sutton, A., Clowes, M., & Martyn-St James, M. (2021). *Systematic approaches to a successful literature review (3rd ed.)*. SAGE Publications.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.

- Correia, A. J., Araujo, F. L. da C., de Jesus, A. R., & Silva, J. M. da. (2025). Issues of quality and access to education in Timor-Leste in the post-independence era. *International Journal of Education and Social Science Studies*, 1(3), 165–170. <https://doi.org/10.60153/ijesss.v1i3.237>
- Damopolii, I., Nunaki, J. H., Nusantara, E., & Kandowangko, N. Y. (2019). Integrating local resources into inquiry-based teaching materials to training students' science process skills. *AIP Conference Proceedings*, 2120(1), 060003. <https://doi.org/10.1063/1.5115703>
- de Deus, J. M. H. (2025). Implementation of STEAM in schools in Timor-Leste: Challenges and opportunities. *Journal of Information System and Education Development*, 3(4), 18–23. <https://doi.org/10.62386/jised.v3i4.168>
- Gabelli, L., Carli, M., Lissandron, G., & Pantano, O. (2025). Teaching scientific practices through low-cost tools: An experiment with high school students. *Journal of Physics: Conference Series*, 2950(1), Article 012019. <https://doi.org/10.1088/1742-6596/2950/1/012019>
- Gomez, M. J. (2025). The impact of inquiry-based learning in science education: A systematic review of student engagement and achievement. *Journal of Education Learning and Management*, 2(2), 353–363. <https://doi.org/10.69739/jelm.v2i2.1143>
- Hofstein, A., & Hugerat, M. (2021). *Teaching and learning in the school chemistry laboratory*. Royal Society of Chemistry. <https://doi.org/10.1039/9781839164712>
- Kırılmazkaya, G., & Dal, S. N. (2022). Effect of hands-on science activities on students' academic achievement and scientific attitude. *International Journal of Education and Literacy Studies*, 10(4), 56–61. <https://doi.org/10.7575/aiac.ijels.v.10n.4p.56>
- Kumari, P., Mwesigye, A., & Balimuttajjo, S. (2024). Science laboratory education and students' perceived behavior towards science education: A review. *Journal of Research Innovation and Implications in Education*, 8(4), 555–561. <https://doi.org/10.59765/pws538jgt>
- Ministry of Education, Youth and Sport of Timor-Leste. (2019). *Basic education curriculum framework*. Government of Timor-Leste.
- Moruk, S. V., & Freitas, Z. da C. (2025). Building inclusive and transformative education in Timor Leste. *International Journal on Education Insight*, 6(1), 9–18. <https://doi.org/10.12928/ijei.v6i1.13234>
- Nawaz, M., Khan, I. A., & Ahmad, M. I. (2024). STEM integration in resource-constrained environments. In M. A. Ashraf and S. M. Tsegay (Eds.), *STEM education: Recent developments and emerging trends*. IntechOpen. <https://doi.org/10.5772/intechopen.113066>
- Pereira, J. C. D., Arantes, J., Hassunuma, Y. N., & Seabra Ferreira, A. S. S. B. (2025). Mapping teaching and learning challenges in laboratory

- environments: A scoping review. *Research, Society and Development*, 14(9), e4614949522. <https://doi.org/10.33448/rsd-v14i9.49522>
- Ramaila, S. (2022). The use of improvised resources in science classrooms in South African township schools. In *Proceedings of the International Conference on Education and New Developments* (pp. 367–370). <https://doi.org/10.36315/2022v1end083>
- Ruqia, B., Bangash, G.A., & Durrani, S. (2025). Impact of laboratory-based teaching on conceptual understanding of biology students at secondary level. *Review Journal of Social Psychology & Social Works*, 3(3), 172–184.
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333–339. <https://doi.org/10.1016/j.jbusres.2019.07.039>
- UNESCO. (2021). *Reimagining our futures together: A new social contract for education*. <https://unesdoc.unesco.org/ark:/48223/pf0000379707>
- UNICEF. (2020). Education in Timor-Leste: Situation analysis report. UNICEF Timor-Leste. <https://www.unicef.org/timorleste/reports/situation-analysis-children-timor-leste>
- Vincent-Lancrin, S., González-Sancho, C., Bouckaert, M., de Luca, F., Fernández-Barrerra, M., Jacotin, G., Urgel, J., & Vidal, Q. (2019). *Fostering students' creativity and critical thinking: What it means in school*. OECD Publishing. <https://doi.org/10.1787/62212c37-en>
- Ximenes, S. M. (2025). Challenges and opportunities in implementing the 2014 primary education curriculum in Timor-Leste: A critical review of teacher perspectives. *International Journal of Applied and Advanced Multidisciplinary Research*, 3(2), 155–164. <https://doi.org/10.59890/ijaamr.v3i2.342>
- Yazdani, N., & Edmonds-Wathen, C. (2025). Supplementary mathematics among adolescents in Timor-Leste. *Mathematics Education Research Journal*, 38(1), 111–134. <https://doi.org/10.1007/s13394-025-00522-7>
- Zhai, X., He, X., & Krajcik, J. (2022). Applying machine learning to assess scientific argumentation: Current status and future directions. *Journal of Research in Science Teaching*, 59(4), 533–562. <https://doi.org/10.1002/tea.21773>

Bio

JOÃO MARIANO HELDER DE DEUS, B.EB., M.Ed., is a Lecturer at the Instituto Católico para Formação de Professores (ICFP), Timor-Leste. His research interests include STEAM education, curriculum development, teacher professional development, and educational policy. Email: jilly143@gmail.com